The Shape Bias in Children with ASD:

Potential Sources of Individual Differences

Ahmed Abdelaziz[1]

Sara T. Kover[2]

Manuela Wagner[1]

Letitia R. Naigles[1]

[1]University of Connecticut

[2]Department of Speech and Hearing Sciences, University of Washington

Ahmed Abdelaziz (corresponding author):	ahmed.abdel_aziz@uconn.edu
Sara T. Kover:	skover@uw.edu
Manuela Wagner:	manuela.wagner@uconn.edu
Letitia R. Naigles:	letitia.naigles@uconn.edu

Abstract

Purpose: Children with autism spectrum disorder (ASD) demonstrate many mechanisms of lexical acquisition that support language in typical development; however, one notable exception is the shape bias. The bases of these children's difficulties with the shape bias are not well understood, and the current study explored potential sources of individual differences from the perspectives of both attentional and conceptual accounts of the shape bias.

Method: Shape bias performance from Potrzeba et al.'s (2015) dataset was analyzed, including 33 children with typical development (*M* = 20 months; *S*D = 1.6), 15 children with ASD with high-verbal abilities (*M* = 33 months; *S*D = 4.6), and 14 children with ASD with low-verbal abilities (*M* = 33 months; *S*D = 6.6). Lexical predictors (shape-side noun percentage from the CDI) and social-pragmatic predictors (joint attention duration during play sessions) were considered as predictors of subsequent shape bias performance.

Results: For children in the low-verbal ASD group, initiation of joint attention (positively) and passive attention (negatively) predicted subsequent shape bias performance, controlling for initial language and developmental level. Proportion of child's known nouns with shape-defined properties correlated negatively with shape bias performance in the high-verbal ASD group, but did not reach significance in regression models.

Conclusions: These findings suggest that no single account sufficiently explains the observed individual differences in shape bias performance in children with ASD. Nonetheless, these findings break new ground in highlighting the role of social communicative interactions as integral to understanding specific language outcomes (i.e., the shape bias) in children with ASD, especially those with low-verbal abilities, and point to new hypotheses concerning the linguistic content of these interactions.

Keywords: shape bias, word learning, language development, vocabulary content, joint attention, parental input

The ‘shape bias’ captures the tendency, observed in both children and adults, to preferentially extend a newly-learned word-object relationship to objects of similar shapes (Landau, Smith, & Jones, 1988). For example, learning that a yellow banana boat is called a *dax* leads one to extend *dax* to orange and green banana boats, but not to yellow honey dippers. The shape bias plays an important role in lexical development, as typically developing (TD) children with earlier and/or more consistent shape biases have been found to have larger vocabularies (Samuelson & Smith, 1999; Smith, Jones, Landau, Gershkoff-Stowe & Samuelson, 2002). The shape bias reflects children’s categorization of distinct but perceptually similar objects around the shape category (Gelman, 2003), and has been proposed to cue the connection between words and taxonomic categories (Booth, Waxman & Huang, 2005; Bloom, 2000; Diesendruk, Markson & Bloom, 2003). This bias has been reported to be absent and/or impaired in children with autism spectrum disorder (ASD), who are characterized by deficits in social communication and interaction, and by excessive repetitive/stereotypical behaviors (APA, 2013). Many aspects of lexical acquisition important in typical development are utilized by some children with ASD; however, differences in language outcomes remain (Arunachalam & Luyster, 2016), including in category organization and semantic processing (Ellawadi, Fein & Naigles, 2015; Gastgeb, Strauss & Minshew, 2006; Kamio, Robins, Kelley, Swainson & Fein, 2007; Kelley Paul, Fein & Naigles, 2006; Naigles, Kelley, Troyb & Fein, 2013). Individual differences associated with the shape bias in ASD could be especially informative for understanding variability in those outcomes because the shape bias is an identified weakness related to lexical and semantic development (Potrzeba, Fein & Naigles, 2015). Our purpose is to provide an overview on what is known about the shape bias in ASD and to generate hypotheses for future research.

In the current study, we explore two possible bases for poor shape bias performance in children with ASD. One postulates that many children with ASD lack the required vocabulary content (i.e., a lexicon containing a certain number and type of nouns) to induce a shape bias (Perry & Samuelson, 2011); the other postulates that many children with ASD lack the ability to discern the referential intent underlying the shape bias (Bloom, 2000). These bases are derived from two differing perspectives on the origins and nature of the shape bias, to which we now turn.

Theoretical Perspectives on the Shape Bias

The development and representation of the shape bias in children and adults is a matter of active debate (e.g., Samuelson & Bloom, 2008; Booth & Waxman, 2008; Colunga & Smith, 2008; Markson, Diesendruck & Bloom, 2008; Horst & Samuelson, 2008). The *Attentional Learning Account* (Smith, 1999) posits that the shape bias emerges because children pay attention to two sets of correlations in their world: First, that objects, especially artifacts, tend to fall into categories organized by their global shapes rather than by their colors, materials, parts, etc., and second, that object names preferentially distinguish objects by shape. Thus, children detect the regularities of both names and physical properties of objects, and abstract the shape bias as a result (Smith, 1999). Researchers fleshing out the Attention Learning Account have demonstrated that the strength of the shape bias varies according to object properties; for example, object complexity decreases shape bias strength (Son, Smith & Goldstone, 2008; Tek, Jaffery, Swensen, Fein, & Naigles, 2012). Moreover, child characteristics are also critical, in that the shape bias has been shown to become operative in development only after children have acquired 50-100 count nouns (Samuelson & Smith, 1999; Smith et al., 2002), supporting the claim that the shape bias emerges from off-line analyses of the noun-object-shape correlations

(Colunga & Smith, 2008). Further scrutiny of typically developing (TD) children's vocabularies has suggested that it is the weight of their 'shape-side' (count and solid nouns; e.g., *cup, block*) nouns over their 'material-side; (mass and nonsolid nouns; e.g., *rain, milk*) nouns that promotes the shape bias (Perry & Samuelson, 2011; Perry & Saffran, 2017). Shape-side nouns are those that reflect categories that are organized by shape similarity, tend to be solid objects, and tend to be count nouns. In contrast, material-side nouns reflect categories organized my material, tend to be non-solid, and tend to be mass nouns. Indeed, it may be the proportion of nouns with certain properties, such as on the shape-side, that relate to shape bias development (Perry & Samuelson, 2011; Samuelson & Smith, 1999).

In contrast to the Attention Learning Account, the *Conceptual Account* of the shape bias suggests that conceptual information about objects is utilized very early in development to predict how object names are extended, and that object shape is treated as a cue to object category (Diesendruck, et al., 2003; Bloom, 2000; Booth, et al., 2005). This shape-as-cue account acknowledges that shape is an imperfect cue to object category, and suggests that it is children's early conceptual knowledge, particularly about causal relations among specific properties (e.g., that bottles tend to be long and narrow because they are meant to be held by human hands), that undergirds their shape bias performance. Support for this perspective with respect to word learning comes from three sets of research findings. First, infants and toddlers with fewer than 50 count nouns in their vocabularies have been shown to extend novel nouns on the basis of shape (Booth et al., 2005, 2008); thus, the conceptual link between shape and object kind seems to be available close to the onset of word learning (pre-dating the sorts of analyses required by the Attention Learning Account). Second, when objects of the same category have dissimilar shapes, preschoolers show sensitivity to conceptual information such as animacy

(Booth & Waxman, 2008) or causal origins (Diesendruck et al., 2003), and that information overrides the shape cue in those cases (see also Cimpian & Markman, 2005). Third, preschoolers show sensitivity to the referential intent of an object's creator or namer; that is, objects made or named intentionally are more likely to yield a shape extension than objects made or named accidentally or incidentally (Diesendruck et al., 2003; Gelman & Bloom, 2000; Gelman & Ebeling, 1998; Keates & Graham, 2008; Markson et al., 2008).

Shape Bias Performance in Children with ASD

Regardless of perspective, theorists agree that the shape bias is a) pervasive among TD toddlers and preschoolers, b) a strategy important for successful vocabulary growth, and c) a potential index of the categorical organization of the lexicon. Among children with ASD, though, the disinclination to extend a word based on object shape has been documented for some time. Tek, Jaffery, Fein, and Naigles (2008) examined the shape bias in 14 children with ASD starting at an average age of 33 months. They presented novel object triads (target, shape match, color match) in two blocks in an Intermodal Preferential Looking (IPL) task (Naigles & Tovar, 2012). During the No-Name block, the targets were introduced by "Look at this!" and the test objects were presented simultaneously side-by-side, paired with the audio "Which one looks the same?" During the subsequent Name block, the targets were introduced by a novel label ("Look at the dax") and the test objects were paired with 'Find another dax". Over the course of four longitudinal visits, the children with ASD, as a group, never demonstrated a shape bias; in contrast, TD 20-month-olds matched on language at Visit 1 looked longer at the shape match during the Name trials relative to the No-Name trials for three of their four visits. In a follow-up study, Potrzeba, et al. (2015) reported that a larger sample of toddlers with ASD tested over a longer period of time (six visits, all four months apart) also failed to show a shape bias at the group level whereas the larger set of TD children now showed a shape bias at all four visits they were tested. Recent investigations in the United Kingdom have provided additional corroboration of the difficulties that even school-age children with ASD have with demonstrating a shape bias (Hartley & Allen, 2014; Field, Allen, & Lewis, 2016a, b).

Research investigating the bases for the absence of a shape bias in children with ASD has primarily targeted a number of aspects of the Attention Learning Account as candidate explanations, with mixed results. For example, Potrzeba et al. (2015) performed item analyses of their object stimuli, but found no evidence that the shape bias strength of the children with ASD varied by complexity of the objects. Moreover, although individuals with ASD frequently have difficulties focusing on global properties such as shape (Frith & Happé, 1994), Potrzeba et al. (2015) reported that the children with ASD in their study looked longer at the shape match than the color match during a number of the No-Name trials, indicating that they were sensitive to the overall shape similarity between the target and shape match.

Shifting the focus to the children's characteristics, investigations have documented that children's shape bias strength has been found to be positively related to their expressive (CDI) and receptive (Mullen, British Peabody Vocabulary Test) language levels, both concurrently (Field et al., 2016a; Potrzeba et al., 2015; Tek et al., 2008) and longitudinally (Potrzeba et al., 2015). These latter findings support the Attention Learning Account, and suggest that many of the children with ASD in Potrzeba et al.'s (2015) study were simply not advanced enough, linguistically, to abstract a shape bias (see also Field et al., 2016a). However, two additional facts remain at odds with this conclusion: First, many children with ASD did have noun vocabularies over 100 words, yet contrary to Samuelson & Smith's (1999) prediction, did not demonstrate a shape bias (Tek et al., 2008). Second, initial scrutiny of the children's vocabulary content, via a coding of their shape-related vs color-related words, revealed no relationship between content and shape bias strength (Potrzeba et al., 2015). What has not yet been performed, though, is a vocabulary content analysis akin to Samuelson and Smith's (1999), in which 'shape-side' and 'material-side' words are considered as predictors of shape bias strength in children with ASD. The current study sought to compare proportions of 'shape-side' and 'material-side' words between children with ASD and children with TD (who on average successfully demonstrate a shape bias) and to utilize these proportions as possible predictors of shape bias in the children with ASD.

Less research has examined the Conceptual Account with the goal of explaining the absence of a shape bias in children with ASD. Field et al. (2016b) demonstrated that school-age children with ASD were able to extend novel words via an object's function, suggesting sensitivity to object kind even without a shape cue; curiously, though, this behavior was strongest among children with ASD with *lower* language levels. Furthermore, many of the children with ASD in the Potrzeba et al. (2015) dataset who did not show a shape bias were nonetheless able to increase their vocabularies over the two years of the study, as well as learn novel words via principles such as the noun bias (fast mapping words to objects over actions) and syntactic bootstrapping (using syntax to fast-map verbs onto causative over noncausative actions; Naigles, Kelty, Jaffrey & Fein, 2011; Naigles & Fein, 2017; Naigles & Tek, 2017; Tek et al., 2008; Tek, Mesite, Fein & Naigles, 2014). Taken together, these findings suggest that children with ASD do have access to the conceptual knowledge underlying a number of word learning principles; hence, their poor shape bias performance cannot be attributed to pervasive conceptual impairments (see also de Marchena, Eigsti, Worek, Ono & Snedeker (2011) for supporting evidence with respect to mutual exclusivity).

We next consider another component of the Conceptual Account; namely, the role of referential intent in children's manifestation of the shape bias. The core idea is that object labels that are intentionally provided will typically refer to that object's kind or category, and for many of the categories relevant to young children, this will be indexed by that object's shape (Bloom, 2000; Markson, Diesendruk & Bloom, 2008). Indeed, TD toddlers have been shown to extend novel labels more consistently to same-shaped objects if the labeled object was intentionally created or named (someone painted a picture of X) rather than accidentally (someone splashed some paint and it looks like X; Gelman & Bloom, 2000; Gelman & Ebeling, 1998). This intentional/non-intentional contrast has also been demonstrated for TD toddlers during initial word-object fast mapping (Diesendruck, Markson, Akhtar & Reudor, 2004; Nilsen, Graham & Pettigrew, 2009; Tomasello & Barton, 1994). However, both Surian (2012) and Field et al. (2016a) have suggested that children with ASD are not sensitive to this contrast, as their 10-year-old participants (with verbal mental ages of 4-5 years, so somewhat lower functioning) performed similarly in intentional vs. incidental contexts. Surian (2012) attributed this lack of sensitivity to the well-attested difficulties that children with ASD experience with theory of mind and pragmatics tasks, and, like others, further linked these difficulties with developmentally earlier impairments in triadic joint attention (Baron-Cohen, 1997; Tager-Flusberg, Paul & Lord, 2005). This line of argument suggests that the intentional/non-intentional distinction that reveals the presence of referential intent (which then facilitates shape extensions of novel object labels) may be impaired in children with ASD for the same reasons that joint attention is impaired. That is, in order for children to specifically distinguish the intentional creation and/or naming of specific objects, they must first manifest some understanding of their own and others' intentional acts and communication.

In the current study, we explore possible connections between the shape bias difficulties of the children in the Potrzeba et al. (2015) dataset and their understanding of referential intent by way of assessing individual differences in the children's engagement in triadic joint attention (JA), in which child and adult alternate gaze between each other and an object, and so demonstrate a shared perspective that concurrent communications are intended to refer to that object (Bruner, 1975). In TD children, triadic JA can be observed beginning in late infancy, and such JA episodes have been shown to have facilitative effects on both general and specific language development. For example, infants and toddlers who engage in laboratory versions of these episodes more successfully acquire the words spoken during them, and children who engage in more of these episodes with their caregivers subsequently are rated by those caregivers to have larger vocabularies (Morales, Mundy, Delgado, Yale, Neal & Schwartz, 2000; Akhtar, Dunham & Dunham, 1991; Tomasello, 1995; see Clark, [2015] and Graham, San Juan & Vukatana [2015] for recent reviews).

As mentioned above, JA behaviors are generally impaired in children with ASD (Lord & Magill-Evans, 1995; Lawton & Kasari, 2011); moreover, variability in joint attention and engagement has been consistently shown to be predictive of variability of general language development in children with ASD (Adamson, Bakeman, Deckner, & Romski, 2009; Adamson, Bakeman, Suma, & Robins, 2017; Charman, Baron-Cohen, Swettenham, Baird, Drew, & Cox, 2003; Dawson et al., 2004; Mundy, Sigman, Ungerer, & Sherman, 1987; Mundy, Sigman, & Kasari, 1990; McDuffie & Yoder, 2005; Luyster, Kadlec, Carter, & Tager-Flusberg, 2008; Siller & Sigman, 2008; Toth, Munson, Meltzoff, & Dawson, 2006). Both Responding to Joint Attention (RJA: when a child follows the attentional focus of the social partner) and Initiating Joint Attention (IJA: when a child directs the social partners' attention to an object or event;

Corkum & Moore, 1995) have been found to be predictive of later language, although sometimes only RJA (Mundy et al., 1987; Luyster et al., 2008; Mundy et al., 2003; Siller & Sigman, 2008) or only IJA (Toth et al., 2006; Mundy, Block, Delgado, Pomares, Van Hecke, & Parlade, 2007; Kasari, Paparella, Freeman, & Jahromi, 2008; Malesa, Foss-Feig, Yoder, Warren, Walden, Stone, 2013; Naigles et al., 2016) reaches significance, and sometimes RJA and IJA are not distinguished (Charman et al., 2003; Dawson et al., 2004). Interestingly, the language outcomes of these studies have generally involved standardized assessments, such as the Reynell Developmental Language Scales (1985), the Mullen Scales of Early Learning (Mullen, 1995), the Peabody Picture Vocabulary Test (Dunn & Dunn, 1997), or the MacArthur Bates Communicative Development Inventory (CDI; Fenson et al., 1991). One exception comes from Naigles et al. (2016), who found that preschoolers with ASD who engaged in longer episodes of IJA also produced fewer pronoun reversals. Given JA's link to intentionality and the Conceptual Account's predictions of the role of referential intent recognition in the emergence of the shape bias, we considered the possibility that children who engage in more and/or longer bouts of JA would also show stronger performance with the specific measure of the shape bias. Of course, referential intent includes a broader construct than just JA; thus, the current study was not designed to directly test the role of referential intent in the emergence of the shape bias, but instead to examine one early developmental skill as a possible source of individual variability in shape bias performance in children with ASD.

Current Study

Using a heterogeneous sample of children with ASD, we examine two potential correlates of individual differences in the shape bias, one inspired by the Attention Learning Account (i.e., proportion of solid+shape and nonsolid+material nouns understood) and one inspired by the Conceptual Account (i.e., duration of episodes of shared attention). Rather than a definitive test of the Conceptual Account versus the Attention Learning Account, we drew from both perspectives because this work is meant to be hypothesis-generating, shedding some initial light on the range of factors that might influence mechanisms or trajectories of language development, as they relate to the shape bias, among individuals with ASD. We focus on understanding the individual differences in shape bias performance reported by Potrzeba et al. (2015) manifested at Visit 4 of a larger longitudinal study, because this was the last visit at which both children with TD and ASD viewed the shape bias video, and because individual differences in shape bias performance at this visit predicted later language (Potrzeba et al., 2015). We assessed both IJA and RJA because of documented differences in their relationships with language development in both TD children and children with ASD (Mundy, et al., 1987; Toth et al., 2006).

In addition to analyzing the overall sample of participants with ASD, we considered children with ASD with high-verbal and low-verbal abilities separately using subgroups of children with ASD above and below the median on expressive language ability. These subgroups were created in light of evidence that this is a meaningful distinction among children with ASD (Ellis Weismer & Kover, 2015; Tek et al., 2014; Kjelgaard & Tager-Flusberg, 2001; Tager-Flusberg, 2006), that these predictors of later language may differ for children who are minimally verbal versus fluent (i.e., at earlier or later stages of language development; Adamson et al., 2017; Haebig, McDuffie, Ellis Weismer, 2013; Hoff & Naigles, 2002; Rowe, 2012), that these subgroupings themselves are related to later outcomes (Tager-Flusberg, 2006), and that distinguishing among groups of children in other populations based on expressive language ability relates to differences in shape bias performance (e.g., Collisson, Grela, Spaulding, Rueckl & Magnuson, 2015; Jones, 2003).

We ask: To what extent do early lexical patterns of acquisition (i.e., proportion of shape- or material-side nouns) or early social pragmatic skills (e.g., RJA, IJA) predict later successful shape bias performance in children with high verbal skills and low verbal skills? Specifically, for children in TD, high-verbal ASD, and low-verbal ASD groups, are lexical properties of known words and engagement in joint attention correlated with subsequent shape bias performance? Further, for each group, do lexical properties and joint attention, assessed during the first visits of this longitudinal study, account for unique variability in later shape bias performance after taking into account overall developmental level and language ability?

Methods

Participants

Thirty-three typically developing (TD) children (4 females; *M* age at Visit 1 = 20.3 months, *S*D = 4.5, Range = 18 - 23) and 29 children with ASD (4 females; *M* age at Visit 1 = 33 months, *S*D = 5.6, Range = 18 - 42) contributed data across four visits, each of which occurred in the child's home at four-month intervals. Children with ASD were recruited through treatment facilities and schools in Connecticut, Massachusetts, Rhode Island, New York, and New Jersey; participants in the TD group were recruited locally from a database of children at the University of Connecticut Child Language Lab. The children were from upper and middle SES families, and the families are primarily Caucasian; years of parental education did not differ significantly among the groups (*p*s > .5). Participants with ASD had been diagnosed by community professionals prior to the beginning of the study, with confirmation from the Autism Diagnostic Observation Schedule (ADOS; Lord, Rutter, Goode, Heemsbergen, Jordan, Mawhood &

Schopler, 1989). According to the ADOS, 19 children were classified as having autistic disorder (ADOS score > 12) and 10 children were classified as on the autism spectrum. At Visit 1, children with ASD and TD did not differ on the number of nouns produced according to parent report, described below, $t(60) = .58$, $p = .564$, $d = .15$, variance ratio = 0.78. See Table 1 for participant characteristics.

Language subgroups for participants with ASD. To allow examination of predictors of shape bias separately for those with higher or lower language abilities, subgroups were created based on expressive language. These two ASD subgroups were created using a median split of the children's raw scores on the Expressive Language subtest of the Mullen Scales of Early Learning (described further below). Raw scores were used instead of standard or age-equivalents because we wanted to differentiate the children based on their actual progress in language development rather than on how closely this progress matched their chronological ages (Perryman et al., 2013; Landa & Garrett, Mayer, 2006; Naigles et al., 2017). Children whose scores were above the median were designated 'high-verbal' and those whose scores were below the median were designated 'low-verbal'. The high-verbal group was comprised of 15 participants; the low-verbal group was comprised of 14 participants; see Table 1.

Standardized Measures

The ADOS (ADOS; Lord et al., 1989) is a semi-structured interaction designed to provide opportunities to observe behaviors and symptoms characteristic of ASD. It consists of a series of activities that encourage social interaction and communication. The ADOS (Module 1) was administered at Visit 1 to confirm community diagnosis of ASD.

Also administered at Visit 1, the Mullen Scales of Early Learning (MSEL; Mullen, 1995) measure aspects of development, including visual reception, expressive and receptive language, and motor development for children from birth to 5 years. The MSEL provides both standard scores (T scores) and age-equivalents for each subtest; however, in the current study, raw scores were used in all analyses, including as the basis for the division into high-verbal and low-verbal subgroups of participants with ASD.

The MacArthur Bates Communicative Development Inventory (CDI; Fenson, Bates, Dale, Marchman, Reznick, & Thal, 2007) provides a parent report of early language development. The infant version (Words and Gestures) of the CDI, designed for TD children from 8 to 16 months of age, was utilized at Visit 1. The CDI had been mailed to parents and was collected at the end of the session. The infant version includes a comprehensive vocabulary checklist, including nouns, verbs, adjectives, pronouns, prepositions, and quantifiers, yielding an estimate of receptive and expressive vocabulary size. As stated above, the TD and overall ASD groups did not statistically differ on number of nouns produced at Visit 1.

Shape Bias Task

As described by Potrzeba et al. (2015) and Tek et al. (2008), the IPL assessment of the shape bias was administered at the beginning of each home visit (see also Naigles & Tovar (2012) for details of the IPL setup and procedures).

As mentioned above, this task tested the shape bias by presenting a novel label paired with an unfamiliar object and then testing extension of that novel label by presenting, side-by-side, one object of the same shape, but a different color, and another object of the same color, but a different shape. These types of test trials are referred to as Name trials: “Where is the *dax*?” Five novel label-object pairs were presented and tested in this way. Prior to presentation of the Name trials, control or ‘No Name’ trials were presented, during which the children’s non-label-influenced grouping preferences (if any) are observed. These trials began with the unfamiliar object paired with "Look at this one!" Then during the test trials, the same-shape and same-color objects were presented side-by-side and the child was asked "Which one looks the same?" The five sets of No Name trials preceded the five sets of Name trials; the sets differed in the ordering of the items. A label-guided shape bias is demonstrated by children looking more to the same-shape object in the Name trials relative to the No Name trials.

The IPL coding for the task is described in detail by Tek et al. (2008; see also Potrzeba et al., 2015). For the current study, the same measure of shape bias performance was used as in those previous studies; this was calculated as the difference score of the proportion of looking to the matching shape relative to looking to the shape or color match in the Name trials, minus the same proportion in the No Name trials, based on the children's performance at Visit 4. Although the shape bias task was administered at every visit of the study for participants with ASD, performance at Visit 4 was selected for the current analyses because it was the last visit at which the task was administered to both the children with ASD and the TD children. At Visit 4, the TD children were an average of 32.60 months old and the children with ASD were an average of 45.32 months old. The children's mean shape bias scores are presented in Table 1; as reported in Potrzeba et al. (2015), the TD group's score was significantly different from zero whereas that of the children with ASD was not.

Coding

Lexical Properties of Vocabulary

Putative predictors of later shape bias were created by coding nouns from the CDI (n = 209) following Samuelson and Smith (1999) for each toddler's lexicon. Note that the Samuelson & Smith (1999) study utilized the Words and Sentences form, not the W&G form, as was the case here; however, the same word categories were coded: animal names, vehicles, toys, clothing, body parts, furniture and rooms, small household items, and outside things. The proportion of nouns characterized by solid+shape (e.g., cup, block), nonsolid+material (e.g., rain, milk), solid+count (e.g., toy, garden), and nonsolid+mass (e.g., snow, coffee) properties was calculated per child. In the current study, six native English-speaking adults coded each noun from the CDI according to syntax (count vs mass), solidity (solid vs non-solid), and category organization (shape vs material). Consensus rules were applied for solidity, syntax, and shape/material/color, such that when 4 of 6 agreed, a code was assigned. Based on the six coders with no overrides of consensus rules, of the 209 nouns on the CDI W&G form, 181 were coded as solid (86.6%), 9 were coded as nonsolid (4.3%), and 19 were coded as ambiguous (9.1%). With respect to syntax, 170 were coded as count nouns (81.3%), 20 as mass nouns (9.6%), and 19 as ambiguous nouns (9.1%). Regarding category organization, 145 were characterized by shape, 29 by color, 32 by material, and 43 as being ambiguous (proportions not given because these characteristics were not mutually exclusive). Ambiguous nouns were not included in any analyses. We counted the number of solid+shape (142), nonsolid+mass (7), solid+count (158), and nonsolid+material (7) nouns, following Samuelson & Smith (1999), contained in each child's lexicon. For these four categories of nouns, we calculated the proportion of the child's noun vocabulary comprised of nouns in each category (e.g., solid+shape words understood/total nouns understood). Descriptive statistics are presented in Table 2.

In the current study, we focused on vocabulary comprehension (i.e., words marked as "understands", not "understands and says") because the dependent variable of interest (shape bias) is also based on language comprehension, and not production. In addition, not all participants contributed data to estimates of lexical production, and we wanted to include as many children as possible. Likewise, we focus on the solid+shape versus nonsolid+mass distinction given the focus on shape bias per se. Thus, the variables of interest for lexical factors were the proportion of solid+shape nouns understood and the proportion of nonsolid+material nouns understood. However, these proportions were missing for one participant with TD and two participants with ASD (both in the high-verbal subgroup) whose parents reported that they understood all nouns on the CDI; as such, sample sizes indicate analyses from which these participants were excluded.

Joint Attention from Parent-Child Play

A 30-minute semi-structured parent-child play session in the participant's home, completed at Visits 1, 2 and 3, was the basis for estimates of joint attention. The first five minutes and last ten minutes (15 minutes total) of the parent-child play sessions involved free play, in which the caregivers were instructed to play with their children as they normally would. The middle 15 minutes followed the structure of the Screening Tool for Autism in Two-year-olds (STAT, Stone, Hoffman, Lewis, & Ousley, 1994). The STAT consists of 12 play-based activities that involve the child in pretend play with dolls, interactive play with a ball or truck, imitative action play, and requests and joint attention (e.g., pointing, reaching, etc.). To ensure that the caregivers followed this structure, the experimenter handed cards to caregivers which stated what the caregivers should be doing with their children.

Three types of child attentional states were coded based on the play session: Responding to Joint Attention (RJA), Initiating Joint Attention (IJA), and Passive Attention (PA). In each case, the derived variable reflected the duration of time the child was engaged in that particular attention state during the play session (Naigles, Cheng, Rattanasone, Tek, et al., 2016; see also Adamson et al., 2009; 2017). Although the frequency of each was calculated, duration was selected as the primary dependent variable because it was less susceptible to floor effects and has been shown to predict other aspects of later language ability (e.g., pronoun use; Naigles et al., 2016). The coding scheme for RJA and IJA was adapted from Roos, McDuffie, Ellis Weismer, & Gernsbacher (2008), which extended the Early Social Communication Scales (ESCS, Mundy, Delgado, Block, Venezia, Hogan, & Seibert, 2003) to measure joint attention in a more naturalistic environment, such as a parent-child play session.

RJA. During the play sessions, RJA behaviors included children's turning or gaze switching as a response to parents' verbal directives, which were intended to shift the child's attention to the object that the parent was attending to. Unlike the ESCS, which provides the child with clear behavioral prompts to elicit RJA (i.e., after securing the child's attention, the experimenter used pointing or verbal prompts such as "Look, *child's name*!"), in a play session with a parent, the verbal directives were less systematic and varied widely. They included calling the child's name, using imperatives (e.g., "Look!";"Put the blocks together!"), questions (e.g., "Do you wanna play with the baby?"; "What is this?"), or simple comments (e.g., "This is such a nice car!"). In this study, the focus was on RJA behaviors produced by the child in response to their parents' verbal directives; thus, RJA was coded regardless of whether the parent pointed or gestured along with the verbal directive.

IJA. IJA coding during the play sessions included the child making eye contact with the parent while manipulating/touching an object, alternating gaze between the object and the adult, pointing to an object, or holding an object and showing it to the parent. One of the differences between the ESCS and the current IJA coding from play sessions was that, in the current study, eye contact in the play sessions had to accompany both pointing and showing behaviors to make sure that the child was initiating joint attention to share interest with the parent rather than independently exploring the objects (Roos et al., 2008). Moreover, because many of the participants in this study were verbal children, IJA behaviors also included initiating joint attention through language (e.g., “What is this?”; “I wanna play with the car.”).

PA. In Roos et al. (2008), a trained experimenter played with the child and ensured that responses to joint attention occurred by repeatedly providing joint attention opportunities until the child responded. In the current study, the caregivers were playing with their children in a naturalistic way, rather than with a scripted protocol like trained experimenters. Therefore, there were instances in which the child did not overtly respond to their caregivers’ bids for joint attention (e.g., putting a toy in front of the child, putting the child’s hands on the toy, turning on a toy). These instances were coded as episodes of PA because they comprised instances of interaction irrespective of the child’s reciprocation. More specifically, the PA behaviors included instances in which parents were attempting to guide their children’s attentional focus when the children were not overtly following their parents’ attentional bids, regardless of whether the child was not engaged at all (as in child disengagment) or was exclusively engaged with another object (as in object engagement; Adamson et al., 2009). For example, one instance of PA included the parent turning on a remote car and the child playing with it without displaying any joint attention behaviors such as eye contact. Without eye contact or a verbal response, it is difficult to determine if the child’s behavior is in response to the parent’s attentional bid or to the movement of the toy itself. Thus, PA was used to capture these cases. PA differs from RJA in that, for PA, the child does not subsequently interact with his/her parents by talking to them, pointing, showing, or making eye contact, despite the parent’s attempt to guide the child’s attention. PA also differs from supported joint engagement, because in supported joint engagement, the child and caregiver seem actively involved with the same object or event because the child’s actions follows caregiver suggestions or actions (Adamson et al., 2009) whereas in PA, the child does not seem to be actively involved with the same object or event as the caregiver because the child's actions do not follow the caregiver's suggestions or actions.

The dataset was coded for JA in two waves. Half of the sample (105 recordings) was coded by Saime Tek (Tek, 2010) for attention measures on a frame-by-frame basis using ELAN (https://tla.mpi.nl/tools/tla-tools/elan/), which is a program developed to code language-specific behaviors from video interactions. Three well-trained undergraduate students then re-coded 14% of these recordings for reliability (n = 14 children, randomly selected across visits). To prevent bias, the reliability coders were blind to the children's diagnosis. The Pearson r for correlations among joint attention coders ranged from .719 to .920, ps < .01. The other half of the recordings were coded by the first author after extensive training from Dr. Tek to ensure that the same procedures were followed. One undergraduate student then re-coded 52 of these recordings (i.e., visits 1 and 3 for 26 children) after being trained by the first author, yielding an inter-coder Cohen's kappa of 0.67 (substantial agreement). Discrepancies were then resolved by discussion. Examples of one RJA, one IJA, and one PA episode are presented in Table 3.

Resulting variables from parent-child play for joint attention. The three independent variables of interest were derived by averaging scores from Visit 1, Visit 2, and Visit 3 for each participant; we combined the scores across visits because of floor effects at Visit 1. Average IJA time was defined as the total amount of time in seconds the child spent in IJA during the 30-minute play session across Visits 1 through 3. Likewise, average RJA and average PA time were defined as the total amount of time the child spent in RJA or PA, respectively.

Analysis Plan

To understand the nature of the predictors in these samples of children with ASD and TD, we first assessed between-group and (for lexical properties) within group differences. That is, for lexical properties, we used within-group paired-samples *t*-tests to establish the extent to which children understood more shape-side nouns than material-side nouns, and then tested the extent to which these lexical properties differed between the groups. We investigated the possibility that the groups had differential relationships between solid+shape and nonsolid+material (allowing an interaction between group and characteristic) in 2 X 2 ANOVAs for group (TD vs ASD; TD vs high-verbal ASD vs low-verbal ASD) and lexical factors (solid+shape/nonsolid+material). For the joint attention measures, we used independent-samples *t* tests and one-way ANOVAs to test the extent to which RJA, IJA, and PA differed between the groups.

To investigate the pairwise relationships between shape bias performance and the lexical and joint attention predictors, we conducted bivariate correlations for the three JA measures, the two lexical measures, and Visit 4 shape bias. Analyses were completed separately for TD and ASD groups, as well as the high-verbal and low-verbal subgroups of children with ASD. Next, hierarchical regressions were performed with subsequent shape bias as the dependent variable, so that the contributions of the predictors of interest could be assessed within the same model (e.g., to account for potential collinearity among predictors). We first entered initial developmental level (MSEL Visual Reception raw score) and initial language (MSEL Receptive Language raw score) into the models because these might be expected to predict shape bias performance, themselves. We then added the predictors of interest that had be found to be significant in the pairwise correlations.

Results

Lexical and JA Descriptives and Group Comparisons

We found that both children with ASD and children with TD understood more shape than material words, more solid than nonsolid nouns, and more count than mass nouns, *p*s < .001, *d*s > 3.0. This result also held true when considering the high-verbal and low-verbal subgroups of children with ASD separately, *p*s < .01, and thus was consistent with the patterns in typical development reported by Samuelson and Smith (1999). Figure 1 shows the proportion of solid+shape and nonsolid+material nouns understood relative to total noun comprehension for each group. Moreover, there were no statistical differences between groups, nor interactions between lexical properties of nouns understood (proportion of solid+shape with nonsolid+material) and group (TD vs. ASD; TD vs. ASD high-verbal vs low-verbal), *p*s > .10. That is, there were neither group differences in proportions of shape or material nouns, nor interactions between group and proportions of dominant (solid+shape) vs. minority (nonsolid+material) characteristic nouns within their lexicons.

Between-group comparisons were also conducted on the JA time measures; the results are presented in Table 4. TD children engaged in significantly longer episodes of IJA than the full group of children with ASD, as well as longer episodes than the low-verbal children with ASD, whereas the two subgroups with ASD did not differ. TD children also engaged in significantly longer episodes of RJA than the full group of children with ASD; however, the TD group did not differ significantly from the high-verbal children with ASD on both RJA and IJA time. Furthermore, Tukey's post hoc comparisons (TD vs. high-verbal ASD, TD vs. low-verbal ASD, high-verbal ASD vs. low-verbal ASD) revealed that both TD children and high-verbal children with ASD engaged in significantly longer episodes of RJA than the low-verbal children with ASD, while the high-verbal children with ASD did not differ significantly from the low-verbal children with ASD on IJA time. In contrast, the children with ASD engaged in significantly longer episodes of PA than the TD children, while Tukey's post hoc analyses by subgroup indicated that the low-verbal children with ASD engaged in significantly longer episodes of PA than both high-verbal children with ASD and TD children, who did not differ on this measure.

Correlations between Predictors and Later Shape Bias

Here, we considered the bivariate correlations between the lexical properties from Visit 1, as well as attention states combined across Visits 1 through 3, with shape bias at Visit 4. We report bivariate correlations for TD, ASD, high-verbal ASD, low-verbal ASD for IJA duration, PA duration, RJA duration, proportion solid+shape understood, proportion nonsolid+material understood.

For lexical factors, we found that neither lexical characteristic (proportion of solid+shape nouns understood, proportion of nonsolid+material nouns understood) was a significant predictor of shape bias performance for the group of TD participants or for the ASD group, overall. When split by language status, for the high verbal group, proportion of nonsolid+material nouns understood positively predicted shape bias, $r = .52$, $p = .034$, one-tailed. That is, higher proportions of the minority (nonsolid+material) pattern for high verbal children with ASD correlated with better subsequent shape bias performance.

For the TD children, no significant correlations were found between RJA, IJA and PA measures and shape bias scores. For the ASD group, children who engaged longer in IJA in Visits 1 through 3 had higher shape bias scores, whereas children who engaged longer in PA in Visits 1 through 3 had lower shape bias scores. By subgroup, these correlations were also significant for the low-verbal children with ASD, but not the high verbal children with ASD. No significant correlations were found for RJA. See Table 5.

Regressions Predicting Subsequent Shape Bias

Hierarchical regressions were performed to predict the shape bias performance of the children with ASD at Visit 4, controlling for the children's cognitive ability and receptive language levels at Visit 1 and including only the significant predictors from the bivariate correlations. . This was done separately for each group or subgroup for whom bivariate correlations were significant (in this case, the ASD group as a whole, as well as the high-verbal and low-verbal subgroups).

Based on a significant bivariate correlation, for the high-verbal subsample of participants with ASD, we tested the proportion of nonsolid+material nouns understood. The lexical variable was the final variable in the model after Visual Reception and Receptive Language were controlled. The model was not significant.

We tested IJA and PA as potential predictors for the overall ASD group and the low-verbal subgroup based on significant bivariate correlations. As shown in Table 6, the models for the overall ASD group were not significant. However, for the low-verbal group, as shown in Table 7, two models were significant. In particular, longer durations of IJA positively predicted stronger shape bias performance [F (3,10) = 4.66, d =1.26]. In other words, longer amounts of shared attention, which was specifically initiated by the child, were associated with a stronger subsequent shape bias in children with ASD with low verbal abilities. Moreover, longer durations of PA negatively predicted shape bias performance [F (3,10) = 3.98, d = 1.14], such that longer amounts of shared attention that were not acknowledged by the child, were associated with a weaker subsequent shape bias in low-verbal children with ASD. These relationships are plotted in Figure 2, which shows two distinct patterns. In particular, the pattern in Figure 2a appears to be bimodal, in that approximately half of the low verbal children with ASD engaged in no IJA at all; the pattern of increasing time spent in IJA correlating with increasing shape bias is demonstrated by the other five children. In contrast, the effect of PA negatively correlating with shape bias performance is clearly linear (Figure 2b), with all children contributing to the overall pattern.

Discussion

Children with ASD demonstrate many mechanisms of lexical acquisition that support typical language development; one notable exception to this is the shape bias (Tek et al., 2008; Potrzeba et al., 2015). Reviewing the Attentional Learning and Conceptual accounts of the emergence of the shape bias in TD children led us to consider two components, one from each account, as bases for shape bias variability in young children with ASD: namely, engagement in joint attention and vocabulary contents. Analysis of each component separately revealed that the regularities proposed to support the emergence of the shape bias in TD were present in the vocabularies of children with ASD; in particular, ‘shape-side’ nouns dominated the vocabularies of children in both groups regardless of vocabulary size (Samuelson & Smith, 1999). Moreover, as expected, TD children engaged in longer RJA and IJA episodes than children with ASD; these effects were most pronounced with the low-verbal ASD subgroup. Bivariate correlations between lexical measures and shape bias performance revealed that, for the high-verbal ASD subgroup, the proportion of nouns understood that were categorized as nonsolid+material was positively correlated with later shape bias performance. That is, higher proportions of the *minority* pattern predicted better subsequent shape bias performance in high-verbal children with ASD. Bivariate correlations between the JA measures and shape bias performance demonstrated that, for the ASD group as a whole as well as the low-verbal ASD subgroup, children who engaged in JA episodes initiated by themselves (IJA), for longer durations over Visits 1-3, had higher shape bias scores at Visit 4. Moreover, children who engaged in PA for longer durations had lower subsequent shape bias scores. Finally, hierarchical regressions predicting shape bias performance were conducted with each significant correlate, now also controlling for developmental level and receptive language (i.e., because in the literature, vocabulary and JA are also related to these constructs). The model containing proportion of nonsolid+material nouns was not significant. However, two models including JA measures reached significance, both with the low-verbal ASD group: average duration of IJA positively predicted later shape bias performance, when controlling for initial developmental level and receptive language ability; furthermore, average PA duration negatively predicted subsequent shape bias performance. No significant relationships between the JA measures and shape bias scores were observed for the TD children or for the high-verbal ASD subgroup. In what follows, we consider the degree to which these findings address our exploratory questions concerning the bases of individual differences in shape bias performance in children with ASD.

Lexical predictors of the shape bias in ASD

For the subsample of high-verbal children with ASD, we observed that higher proportions of minority-characteristic nouns in their receptive vocabularies showed promise in positively predicting later shape bias performance. This relationship seems, at first, to be at odds with our predictions and the Attention Learning Account of the shape bias: recall that, following Samuelson and Smith (1999) and Perry and Samuelson (2011), we had predicted that children with more 'shape-side' nouns in their vocabularies would demonstrate a stronger shape bias. We did find that the non-solid+material and non-solid+mass nouns represented a smaller proportion of nouns (compared with 'shape-side' nouns) in the lexicons of the high-verbal children with ASD—as they did for the TD group. It is possible that, for children beyond the earliest stages of language acquisition, acquiring these types of nouns might support a shape bias by highlighting the contrast between 'shape-side' nouns and other nouns. That is, learning some non-shape-organized nouns might throw the dominance of the noun-shape-object pattern into higher relief (see also Samuelson & Smith [1999] and Perry & Saffran [2017] for further discussion). It is also possible that the ability to learn 'material-side' nouns might signal broader strengths in language acquisition that result in trajectories more closely approximating typical development. The current study cannot distinguish between these possibilities and of course, these speculations are offered with caution given the small sample sizes and nonsignificant regression models. However, it is important to note that these findings do not provide clear support that the Attention Learning Account of the shape bias can be extended to explain individual differences in the performance of children with ASD. Finally, the number of nonsolid nouns captured by the CDI is extremely small, which limits the strength of conclusions that can be drawn from the current analyses. Future research might benefit from examining 'against the system' nouns as a next step (Perry & Samuelson, 2011).

Social predictors of the shape bias in ASD

For the ASD group as a whole, but most particularly for the low-verbal ASD subgroup, the IJA and PA measures of shared attention were significantly predictive of subsequent shape bias performance: IJA duration was a positive predictor, and PA duration a negative one. These findings are consistent with our expectations and with the Conceptual Account, that shape bias development is crucially tied to children's understanding of referential intent (Diesendruck et al., 2003). That is, if the shape bias depends, at least in part, on attending to and understanding others' intentions, then the tendency to initiate a shared focus of attention with others would be supportive, and the tendency to ignore a shared focus, as during PA, would be disruptive. These relationships were found to be independent of the children's initial developmental and language levels (note that in the significant models, neither Mullen subscale contributed significantly by itself); thus, they do not reduce simply to effects of early language or cognition on later language or cognition. In addition, our demonstration of a link between IJA and the specific construct of the shape bias both replicates and extends the general IJA-standardized language relationships previously reported in the ASD literature (Bottema-Beutel, Yoder, Hochman, & Watson , 2014; Kasari et al., 2008; Malesa et al., 2013; Toth et al., 2006).

However, the specifics of this IJA-shape bias-PA linkage are not completely clear. According to Diesendruck et al. (2003), the shape bias emerges because children believe that count nouns refer to object kinds, and the object shape is a reliable cue to that object's kind. Indeed, we have preliminary supporting longitudinal evidence for the shape bias—object kind linkage within our TD sample: When these children were five years of age, they were given a classic categorical induction task (Gelman & Markman,1986), and those who performed more consistently at age 5 had demonstrated stronger shape bias performance 2.5 years earlier (Tecoulesco & Naigles, 2018). Object naming and creation that are presented as intentional acts are also more strongly indicative of object kinds—and the shape bias—than their accidental counterparts, and Surian (2012) has proposed that children with ASD's lack of sensitivity to the intentional/accidental contrast derives from their general challenges with intersubjectivity and theory of mind, with JA as a relevant index. However, we raise three issues with JA being the sole explanation for the poor shape bias performance within our ASD group.

First, why did significant relationships between JA and shape bias performance emerge only for the low-verbal ASD subgroup? Scrutiny of Tables 1 and 4 reveals that the high-verbal subgroup manifests similar levels of shape bias variability and RJA/IJA variability as the low-verbal subgroup; therefore, the absence of a significant JA-shape bias relationship is not attributable to little variance (although this might be an explanation for the TD group). Instead, we see similarities between this pattern of findings and that reported by Haebig et al. (2013); in both studies, social/pragmatic effects on word learning were confined to the low-verbal group with ASD. Hoff and Naigles (2002) have suggested that among TD children, too, JA exerts its influence most strongly at the beginning of vocabulary acquisition, when parents do most of the work in guiding triadic communication situations (see also Tamis-LeMonda, Kuchirko & Song, 2014). Possibly, then, the high-verbal children with ASD are relying on different kinds of experiences—such as their accrued vocabulary content—when deciding whether or not to extend words by shape.

Second, there are a number of reports in the literature that understanding of referential intent sometimes leads TD children *away from* a shape bias, especially if the intent highlighted an object function as a cue to object kind. This phenomenon was observed in Diesendruck et al. (2003) and Keates and Graham (2008), among others. Thus, the referential intent-shape bias connection is *malleable* (Markson et al., 2008) even in TD children, and might, for example, be developmentally constrained, (e.g., dependent upon the child's understanding of referential intent, other conceptual knowledge, or language ability).

A third issue is that while JA is traditionally considered to be an index of social pragmatic ability (Tomasello, 1995), recent treatments have also pointed out a cognitive interpretation (e.g., Mundy, 2016). For example, children who can maintain attention on two entities (i.e., an object and their communication partner) for longer periods of time might have a greater cognitive capacity for learning about objects in general. They might be able to spend more time considering the features of specific objects that have been named, which might enable them to successfully extract object shape as a recurring feature. In such a way, our positive IJA effect might actually be construed as supportive of the Attention Learning Account. However, our negative PA effect might tell against this construal, because children engaged in PA for long periods of time have ample opportunity to extract shape features of the objects they are looking at. The key point still seems to be that children who tend to engage in PA tend also not to pay attention to their communication partner—and to the words s/he is uttering.

This finding—that long engagement in PA was disruptive to shape bias performance—led us to revisit some findings concerning the shape bias and object categorization, which do not fit straightforwardly into either the Attention Learning Account or the Conceptual Account. In particular, studies by Gelman and Graham and their colleagues indicate that the *linguistic content* produced during episodes of JA is often crucial for TD children's successful shape bias performance and effective categorical induction. For example, Nilsen, Graham and Pettigrew (2009) reported that TD preschoolers showed more successful fast mapping of novel words when presented with descriptions of the target objects that highlighted specific properties. Graham, Gelman and Clarke (2016) found two-year-olds to be sensitive to the presence of generics (*Blicks drink ketchup*) during JA episodes, in that toddlers who heard these were more likely to extend properties of 'blicks' to novel members of the same category (relative to non-generics). Additionally, Gelman, Coley, et al. (1998) analyzed mothers' speech while engaged in picture book perusal with their two- to-three-year-olds, and found a high proportion of talk about taxonomic relations in this context, particularly when mentioning multiple entities (e.g., "that's a desk; that's a desk, too" (p. 34). Generics were produced at lower rates, but occurred at least once in many dyads.

With this literature as background, we reconsidered the linguistic contents of the JA episodes in our dataset. Compare, for example, the sample IJA and PA episodes in Table 3, which actually involved the same dyad of mother and low-verbal child with ASD. The IJA episode was initiated by the child by handing the mother a book; the child continues to show (nonverbal) engagement throughout by smiling. In the PA episode, the mother follows the child's focus of attention (i.e., the balloon) but the child does not respond, at least overtly. The two episodes are clearly different in length; however, what is also striking is the difference in the content the mother provides. In the IJA episode, the mother introduces multiple objects *and their properties*: the cat says meow, dogs go woof, and the tail waggles. Thus, she is providing linguistic information that highlights object kinds by the use of generics (see also Tare & Gelman, 2010), and contrasts object labels with property/activity labels (Waxman, Shipley & Shepperson, 1991). Both of these kinds of information have been documented as effective, in TD children, in promoting richly structured categories where shape plays a prominent role (Gelman, Star, & Flukes, 2002; Gelman, Chesnick, & Waxman, 2005). In contrast, in the PA episode, the same mother's utterance length is just as long, but her content is repetitive, her verbs tend to be general (*do, have, go*) rather than specific (*blow*), and no generics or other category-relevant information are offered.

Our emerging hypothesis, then, is that the *content* of the IJA episodes may have been more informative about object kinds, and hence the shape bias, than the content of the PA episodes. This hypothesis is in line with recent research demonstrating that children with ASD are sensitive to the linguistic input of their caregivers (see Nadig & Bang [2017] for a recent summary of these findings), as well as with research that is beginning to scrutinize the flow of parent-child joint attention episodes in much more detail (e.g., Adamson et al., 2017; Kaale, Smith, Nordahl-Hansen, Fagerland, & Kasari , 2017). What is unknown is the importance of this highly informative input coming *during IJA episodes* (i.e., initiated by the child and so likely to be of great interest to the child), versus being available during other kinds of interactions as well. Thus, one clear next step is to analyze parental content both 'inside' and 'outside' of JA episodes (including RJA even though these episodes did not contribute to the current models), to see if the pattern we have noticed in these two episodes holds across dyads and across multiple occurrences of the episode types. Moreover, a micro-analysis of the sequences of turns within the episodes is also likely to prove fruitful.

Limitations and Future Directions

The current findings are limited in that they are based on a modest sample of children with ASD, who had limited variability in IJA at the initial visit of the study. Thus, the lexical and JA predictors were not drawn from the same visit, which might have contributed to the fact that the JA findings were stronger than the lexical ones. Further, the analyses based on subgroups of children with ASD with high verbal or low verbal skills were likely underpowered, although effect sizes were moderate to strong. Nonetheless, this study is only the second (after Field et al., 2016a) to examine potential explanations for the absence of a shape bias in children with ASD from both the Attentional Learning and Conceptual accounts of shape bias development; in our case, children's vocabulary content and their social pragmatic abilities. Like Field et al. (2016a, b), we have adduced possible support for both the Attention Learning Account and Conceptual Account, but also highlighted how the Conceptual Account might be further refined by detailed scrutiny of the content of children's vocabularies and their shared attention episodes. Future work should continue to examine the extent to which characteristics of the language input and the child's already acquired language (both receptive and expressive vocabulary) interact to impact further acquisition of both specific and general language skills.

Overall, these findings have implications for understanding individual differences in lexical acquisition for children with ASD, potential differences between high- and low-verbal subgroups of children with ASD, and potential differences or similarities between children with ASD and other populations. For example, both late talkers and children with developmental language disorder (formerly known as specific language impairment) have been shown to lack a shape bias in circumstances in which children with typical language skills demonstrate one (Jones, 2003; Collisson, Grela, Spaulding, Rueckl, & Magnuson, 2015).). It has yet to be determined whether and to what extent the factors that underlie shape bias performance in children with developmental language disorder or ASD overlap. Understanding the timing and weight of those factors will be particularly informative to explaining the observed trajectories of language development in children with ASD or developmental language disorder, as well as, potentially, informing strategies for intervention that are optimally developmentally timed.

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Table 1. Participant Characteristics at Visit 1 and Shape Bias Performance at Visit 4

	TD *n* = 33		Total ASD *n* = 29		High-Verbal ASD *n* = 15		Low-Verbal ASD *n* = 14	
	Mean	(SD)	Mean	(SD)	Mean	(SD)	Mean	(SD)
Age	20.3	(1.63)	33.0	(5.6)	32.81	(4.60)	33.16	(6.62)
Parent education[1]	8.16	(1.91)	7.71	(2.48)	8.00	(1.77)	7.45	(3.00)
CDI Nouns Produced	62.67	(62.10)	52.86	(70.90)	100.07	(71.27)	2.29	(5.62)
ADOS[2]	0.85	(1.52)	14.03	(4.15)	11.73	(3.15)	16.5	(3.72)
Mullen Visual Reception								
Raw scores	26.09	(3.32)	27.6	(5.37)	30.4	(8.08)	23.64	(4.6)
Range	(19 – 32)		(13 – 42)		(20 – 42)		(13 – 31)	
T scores[3]	58.12	(11.52)	37.86	(15.26)	44.93	(12.69)	30.29	(14.45)
Range	(36 – 80)		(20 – 65)		(27 – 63)		(20 – 65)	
Mullen Fine Motor								
Raw scores	22.73	(2.58)	25.14	(4.19)	27.8	(5.81)	23.67	(2.18)
Range	(19 – 28)		(16 – 34)		(20 – 34)		(16 – 27)	
T scores	50.63	(8.81)	33	(14.88)	37	(13.07)	28.71	(15.96)
Range	(36 – 75)		(20 – 76)		(20 – 57)		(20 – 76)	
Mullen Receptive Language								
Raw scores	24.36	(3.47)	19.64	(10.37)	28.4	(9.18)	14.42	(6.04)
Range	(17 – 31)		(2 – 38)		(16 – 38)		(2 – 27)	
T scores	58.12	(11.52)	36.76	(19.10)	47.8	(16.09)	24.93	(14.68)
Range	(28 – 80)		(20 – 74)		(20 – 70)		(20 – 74)	

Mullen Expressive Language								
Raw scores	20.10	(5.09)	16.29	(6.64)	23.2	(6.30)	11.57	(2.24)
Range	(13 – 33)		(8 – 33)		(16 – 33)		(8 – 15)	
T scores	50.15	(12.88)	30.76	(12.87)	39.27	(12.29)	21.64	(4.62)
Range	(30 – 80)		(20 – 64)		(20 – 64)		(20 – 37)	
Shape bias at Visit 4	0.073	(0.122)	0.013	(0.112)	0.046	(0.123)	-0.022	(0.089)

Note. The high-verbal and low-verbal subgroups of children with ASD were created based on a median split of expressive language raw score within the sample on the Mullen.

[1] Number of years of formal education past 8th grade

[2] Cut-off score for classification of autistic disorder is 12; cut-off score for a classification of autism spectrum is 7.

[3] T scores: *M* =50, *SD* = 10.

Table 2. Lexical properties of nouns based on the CDI

	TD *n* = 33			Total ASD *n* = 29			High-Verbal ASD *n* = 15			Low-Verbal ASD *n* = 14		
	Mean	(SD)	Range	Mean	(SD)	Range	Mean	(SD)	Range	Mean	(SD)	Range
Proportion of solid+shape												
Nouns understood	.70[a]	(.11)	.35 – 1.0	.68[b]	(.17)	.00 - .88	.65[c]	(.22)	.00 - .88	.71	(.09)	.50 - .85
Nouns produced	.73	(.10)	.00 - .22	.78[e]	(.14)	.50 – 1.00	.74	(.09)	.50 - .86	.87[d]	(.19)	.50 – 1.00
Prop. nonsolid+material												
Nouns understood	.03[a]	(.02)	.00 - .06	.07[b]	(.13)	.00 - .50	.06[c]	(.13)	.00 - .50	.08	(.13)	.00 - .50
Nouns produced	.06	(.05)	.00 - .22	.08[e]	(.11)	.50 – 1.00	.06	(.04)	.02 - .20	.12[d]	(.20)	.00 - .50
Proportion of solid+count												
Nouns understood	.79	(.09)	.55 – 1.00	.74[b]	(.17)	.00 - .92	.71[c]	(.22)	.00 - .88	.76	(.10)	.50 - .92
Nouns produced	.77	(.10)	.44 – 1.00	.76[e]	(.21)	.00 – 1.00	.78	(.09)	.50 - .89	.71[d]	(.39)	.00 – 1.00
Proportion of nonsolid+mass												
Nouns understood	.03	(.02)	.00 - .06	.06[b]	(.13)	.00 - .50	.06[c]	(.13)	.00 - .50	.06	(.13)	.00 - .50

Nouns produced	.05	(.06)	.00 - .33	.03[e]	(.05)	.00 - .20	.05	(.05)	.00 - .20	.00[d]	(.00)	.00 - .00

[a] $n = 32$

[b] $n = 27$

[c] $n = 13$

[d] $n = 6$

[e] $n = 21$

Table 3. Examples of RJA, IJA, and PA episodes from the dataset		
RJA	IJA	PA
1. Mother: Child's name? 2. Mother: Look. 3. Mother: help mommy build it so mommy can knock it over. 4. *Child: mine* 5. Mother: no mommy. 6. Mother: mommy wants to knock it over. 7. Mother: mommy's turn. 8. Mother: mommy's turn. 9. Mother: 'Name' watch. 10. *Child: yeah.* 11. Mother: watch watch. 12. *Child: xxx yeah.* 13. Mother: mommy's gonna knock the 14. Mother: yeah. 15. Mother: ooo i got it. 16. Mother: I got to it sort of. 17. Mother: go ahead. 18. Mother: can you put the block on? *19. Child: buh buh yeah .* 20. Mother: can you finish the tower? 21. *Child: buh buh yeah.* 22. Mother: buh buh. 23. Mother: I know.	1. *Child gives book to mother* 2. Mother: now you wanna look at the book. 3. *Child nods* 4. Mother: what's that? 5. *Child looks, but does not respond verbally.* 6. Mother: what's that? 7. *Child looks, but does not respond verbally.* 8. Mother: cat says meow, meow. 9. *Child smiles* 10. Mother: that's a dog they go, woof woof woof. 11. *Child smiles* 12. Mother: that's his tail. 13. *Child smiles* 14. Mother: doggies tail waggle waggle waggle tail. 15. *Child smiles*	1. Mother: should we do the balloon? 2. (Mother holds balloon in front of child's face.) 3. Mother: can I blow the balloon? 4. Mother: ah look, look what I have? 5. (Mother blows up balloon and lets it go.) 6. Mother: wow where did it go? 7. (Child does not respond at all.)

Table 4. Means and SDs of joint attention time measures (seconds), and ANOVA results for cross-group comparisons

	TD *n* = 33	**ASD** *n* = 29	**HV ASD** *n* = 15	**LV ASD** *n* = 14	**TD vs ASD**[a]	**TD vs subgroups**[b]
RJA Mean RJA SD RJA Range	966.86 (258.54) (588 – 1426)	654.94 (429.56) (0 – 1330)	911.28 (328.20) (171 – 1330)	380.28 (352.65) (0 – 979)	F (1,60) = 12.33 TD > ASD**	F (2,59) = 19.86 TD > LV ASD** LV ASD < HV ASD**
IJA Mean IJA SD IJA Range	121.68 (91.64) (0 – 391)	43.12 (52.34) (0 – 189)	70.00 (56.40) (0 – 189)	14.32 (27.33) (0 – 84)	F (1,60) = 16.55 TD > ASD**	F (2,59) = 10.75 TD > LV ASD**
PA Mean PA SD PA Range	131.17 (126.53) (2 – 491)	279.44 (265.98) (26 – 947)	149.95 (125.21) (26 – 418)	418.17 (308.90) (32 – 947)	F (1,60) = 8.17 ASD > TD**	F (2,59) = 12.87 TD < LV ASD** LV ASD > HV ASD**

[a] The ANOVA results for across-groups comparison between TD children and children with ASD (the whole group)

[b] The ANOVA results for across-groups comparison between TD children and High-Verbal and Low-Verbal children with ASD, with significant post-hoc comparisons via Tukey's test

** $p < 0.01$

Table 5. Selected bivariate correlations between putative predictors and shape bias performance at Visit 4

	TD Shape Bias $n = 33$	ASD Shape Bias $n = 29$	High-Verbal ASD Shape Bias $n = 15$	Low-Verbal ASD Shape Bias $n = 14$
Proportion of nouns understood characterized as solid+shape.	-.28[a]	-.27[b]	-.19[c]	.06
Proportion of nouns understood characterized as nonsolid+material	.16[a]	.15[b]	.52*[c]	-.31
Average RJA time	-.12	.23	-.26	0.47
Average IJA time	.22	.41*	.19	.66*
Average PA time	.10	-.44*	.05	-.68*

* $p < 0.05$

[a] $n = 32$

[b] $n = 27$

[c] $n = 13$

Table 6. Hierarchical regression for joint attention predicting ASD group shape bias at Visit 4 (n = 29).

Final models:	***B***	***SE(B)***	***β***	**ΔR^2**
Predicting Shape Bias V4[1]				
Mullen Visual Reception V1	< 0.01	< 0.01	0.1517997	
Mullen Receptive Language V1	< - 0.01	< 0.01	-0.2454723	
IJA time	< 0.01	< 0.01	0.4998966	0.1738
Predicting Shape Bias V4[2]				
Mullen Visual Reception V1	< - 0.01	< 0.01	-0.1152412	
Mullen Receptive Language V1	< - 0.01	< 0.01	-0.0907170	
PA time	< - 0.01	< 0.01	-0.5493975	0.1961

* $p < 0.05$

** $p < 0.01$

[1] $F(3,25) = 1.99$, cohen's $d = 1.01$
[2] $F(3,25) = 2.29$, cohen's $d = 0.712$

Table 7. Hierarchical regression for joint attention predicting the low-verbal ASD group's shape bias at Visit 4 (n = 14).

Final model:	**B**	***SE(B)***	***β***	**ΔR²**
Predicting Shape Bias V4[1]				
Mullen Visual Reception V1	< 0.01	< 0.01	0.01285269	
Mullen Receptive Language V1	< - 0.01	< 0.01	-0.4054149	
IJA duration[2]	< 0.01	< 0.01	0.79723039	0.5114*
Predicting Shape Bias V4[3]				
Mullen Visual Reception V1	< - 0.01	< 0.01	-0.1262722	
Mullen Receptive Language V1	< - 0.01	< 0.01	-0.2297866	
PA duration[4]	< - 0.01	< 0.01	-0.7868704	0.4726*
* $p < 0.05$				
** $p < 0.01$				

[1] F (3,10) = 4.66, cohen's d = 1.26
[2] t-stat = 3.50, p = .006
[3]. F(3,10) = 3.98, cohen's d = 1.14
[4] t-stat = -3.22, p = .009

Figure Captions

Figure 1. Proportion of Solid+Shape (black) and Non-Solid+Material (white) nouns understood relative to noun vocabulary size in children with TD (top), high-verbal children with ASD (middle), and low-verbal children with ASD (bottom).

Figure 2. Scatterplots of IJA duration (top) and PA duration (bottom) with shape bias performance for low-verbal children with ASD.